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SUMMARY PAGE

THE PROBLEM

To determine the effects of lowered concentrations of oxygen in an artificial atmosphere on the course of dark adaptation.

THE FINDINGS

Reducing the oxygen level to 12% delayed the course of dark adaptation. The final scotopic threshold, however, was not affected.

APPLICATION

Significant reductions in oxygen level can occur in submarines without reducing the final level of night vision sensitivity. However, the speed with which complete dark adaptation is achieved will be reduced.

ADMINISTRATIVE INFORMATION

This investigation was conducted under Naval Medical Research and Development Command Independent Work Unit 61152N - MR000101-5103 with funds provided by the Naval Sea Systems Command. It was submitted for review on 14 October 1989, approved for publication on 26 December 1989, and has been designated as Naval Submarine Medical Research Laboratory Report No. 1151.

ABSTRACT

We performed a double-blind study to determine the effect of hypoxia on the rate of dark-adaptation. The visual thresholds of 10 subjects were measured as they breathed either 21% O_2 or 12% O_2 for 10 minutes in daylight followed by 50 minutes in the dark. The subjects were exposed to the two gases in counterbalanced order on separate days. Reducing the oxygen level to 12% delayed the course of dark-adaptation without changing the final scotopic threshold.

INTRODUCTION

McFarland and Evans (1939) reported that exposure to 11.7% oxygen (O_2) both slows the course of dark-adaptation and raises the scotopic threshold. Hecht, et al. (1945-6) concluded that the scotopic threshold is raised in subjects who breathe O_2 concentrations less than 15%.

We have found, on the contrary, that 12% O_2 does not change the scotopic absolute threshold (Knight, et al., 1987), a difference in results which we attribute to our using a double-blind procedure. Only when subjects breathed 10% O_2 for 20 minutes did we observe a significant effect on scotopic vision (Luria and Knight, 1987).

This leaves open the question of whether or not certain levels of hypoxia simply delay the course of dark-adaptation without raising the final threshold. We have previously measured scotopic thresholds under 12% O_2. In this study, we tested the effect of 12% O_2 on the course of dark adaptation.

METHODS

Subjects. Ten Navy enlisted men completed the study. They were selected as subjects[1] after passing a physical examination that included a chest x-ray, a 12-lead electrocardiogram, a screening test for sickle-cell anemia, a measurement of fasting blood sugar, and a complete blood count. Their mean age was 29.6 $\pm$ 7.3 years, their mean height was 183.4 $\pm$ 9.6 cm, and their mean weight was 87.6 $\pm$ 7.9 kg. One subject, a cigarette smoker, refrained from the use of tobacco for 12 hours before each testing session. The subjects were permitted to wear untinted corrective lenses during testing.

Apparatus. The subject inhaled the gas mixture through a Rudolph 3-way breathing valve (total deadspace = 115 mL) while wearing a noseclip. Leaks around the mouthpiece were checked by monitoring the composition of the expired gas with a Perkin-Elmer MGA 1100 mass spectrometer; this indicated a good seal around the mouthpiece of all subjects. A finger sensor was used to measure the oxygen saturation of arterial blood (S_a, O_2) by a method of pulse oximetry (Novametrix model 500). The finger sensor was covered by a glove to avoid stray light in the darkened booth. A physician monitored the subject's electrocardiogram and S_a, O_2 during the experiments.

The test light was a circular stimulus subtending 30 min visual angle, at the viewing distance of 30 cm. It was presented 10 deg to the left of a pin-point red fixation light. The light source was a projection bulb which was flashed on and off at equal intervals of 0.25 sec to facilitate its recognition. Its luminance was varied with neutral density filters, and its

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[1] The nature and purpose of the study and the risks involved were explained verbally and given on a written form to each subject prior to his voluntary consent to participate. The protocol and procedures for the study were approved by the Committee for the Protection of Human Subjects at the Naval Submarine Medical Research Laboratory, Groton, CT.

dominant wavelength was adjusted to 500 nm with a Corning glass filter. The luminances were measured with a Spectra-Pritchard Photometer model 1980; the dominant wavelength was measured with a Photo-Research PR-703-A spectro-radiometer.

Procedure. There were three practice sessions followed by two experimental sessions on separate days. The only difference between the experimental sessions was the composition of the unknown breathing gas, which was either 21% O_2-balance N_2O_2 or 12% O_2-balance N_2. Five subjects breathed the 21% O_2 first, and five breathed the 12% O_2 first. Each subject was exposed to the two gases at the same time of day on separate days. A double-blind procedure was used; neither the subjects nor the experimenters were told which gas was being administered. Only the attending physician and the mass-spectrometer technician were informed of the gas being administered.

In each experiment, the subject sat comfortably inside a ventilated booth (0.9 x 0.9 x 2.3 m) for the entire procedure. The procedure fulfilled Sheard's (1944) criteria for measuring scotopic sensitivity except that an artificial pupil was not used.

Each experiment began when the subject started to breathe the unknown gas for 60 minutes. After the gas had been inhaled for 6 minutes, the right eye was exposed for 4 minutes to a ground-glass screen subtending 25 deg visual angle on a side at the viewing distance of 120 cm and illuminated to 3.95 $\log_{10} cd/m^2$. Then the booth was darkened, and the subject placed his head in a chin-and-forehead rest which set his eye 30 cm from the test stimulus.

Several minutes of dark adaptation were necessary before the subject could see the red fixation light. When it became visible, the measurement of the dark adaptation curve was begun. A forced-choice procedure was used. The subject was asked to report during which of two consecutive 15-second time periods the stimulus was presented. When he answered correctly, the stimulus intensity was lowered and the procedure repeated. After 40 minutes of dark adaptation, the final threshold was measured using the method of constant stimuli. A series of 5 or 6 intensities at 0.1 log unit intervals was chosen, and each was presented 6 to 10 times in random order. The subject was warned that catch trials would be inserted to preclude guessing. A frequency of seeing curve was calculated, and the 50% detection point taken as the threshold.

The forced-choice procedure was used during the period when the visual sensitivity was changing in order to be able to identify guessing. The method of constant stimuli was not used at this time because it takes too long to determine a threshold with this method; it is, therefore, inappropriate when the threshold is rapidly changing. The method of constant stimuli was used, however, for the determination of the final, absolute threshold. Sensitivity is not constant, and there is time to carry out a careful measurement.

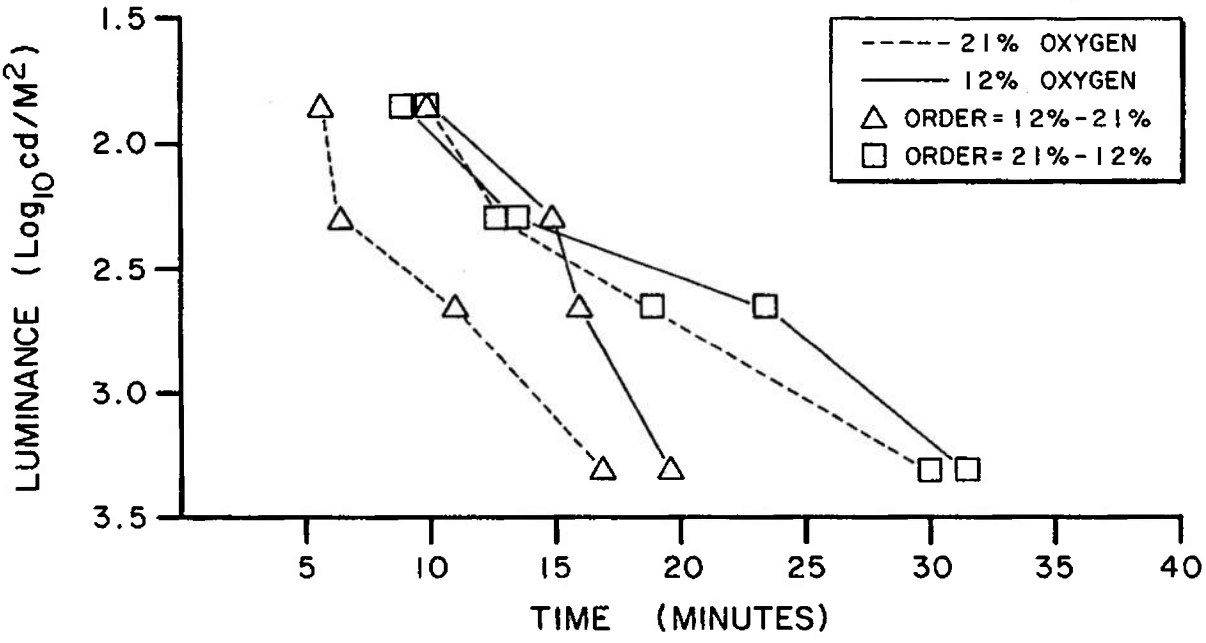

Figure 1. Dark adaptation curves for the two gas conditions and the two orders of presentation. Each point is the mean of the five subjects in each group. Time zero is the point at which the adapting light was extinguished. The subjects had been breathing the gas for 10 minutes.

RESULTS

Physiological Responses. The mean S_aO_2 was 87% in the hypoxia condition and 98% in the control condition when the first light stimuli were detected. They remained constant in both oxygen conditions. This difference was significant ($p < .001$) according to a paired t-test.

The heart rates were higher at the end of the hypoxia condition (81 $\pm$ 10 beats/min) than at the end of the control condition (72 $\pm$ 12 beats/min). This difference was significant ($p < .01$) according to a paired t-test.

Course of Dark Adaptation. The data were divided into categories encompassing the following ranges of luminance: -1.5 to -2.0, -2.0 to -2.5, -2.5 to -3.0, and -3.0 to -3.5 $\log_{10}cd/m^2$. The time taken to respond to a stimulus in each range was recorded. The mean response time for each subject was used when there were several responses in a range.

Figure 1 shows the dark adaptation curves for the two gas conditions starting when the adapting light was extinguished and broken down into the two orders of presentation.

The data were tested with a repeated-measures analysis of variance with gas condition, order or presentation, and luminance level as within subjects variables. The course of dark adaptation was faster during exposure to 21% than 12% oxygen for both orders of presentation, but the difference was greater for the subjects who were exposed to 12% oxygen first. Subjects who were first exposed to 21% oxygen took longer to dark-adapt to luminances of -3.0 to -3.5 $\log_{10}cd/m^2$ than those who were first exposed to 12% oxygen ($F = 7.06$, $p < .01$). The statistical analysis showed, however, that neither the gas nor the order of presentation had an effect above -2.0 $\log_{10}cd/m^2$. The effects of the gas mixture were most apparent at -2.0 to -3.0 $\log_{10}cd/m^2$. Response time was longer under the hypoxia condition in the range of -2.5 to -3.0 $\log_{10}cd/m^2$ ($F = 6.3$, $p < .05$) and tended to be longer in the range of -2.0 to -2.5 $\log_{10}cd/m^2$ ($F = 4.1$, $p < .08$). There was an interaction of the gas condition and luminance according to Pillai's test ($p < .03$).

Scotopic threshold. After 30 to 35 minutes, there were no further responses from the subjects using the forced-choice procedure. The subjects continued to breathe the gas mixture, and after about 40 minutes of exposure, the final 10 minutes were occupied in measuring the absolute scotopic threshold. The mean final scotopic thresholds were -3.56 $\pm$ .18 $\log_{10}cd/m^2$ for the control condition and -3.32 $\pm$ .16 $\log_{10}cd/m^2$ for the hypoxic condition. This difference was not significant ($p < .25$) according to a paired t-test.

DISCUSSION

Our previous studies showed that 10% O_2 raises the scotopic threshold (Luria and Knight, 1987), but higher oxygen levels do not (Knight, et al., 1987). These studies provided no data, however, on the course of darkk adaptation. The results of the present study again show that 12% does not degrade the final scotopic threshold, but it does change the course of the dark adaptation curve. This supports the report of McFarland and Evans

(1939) that hypoxia delays dark-adaptation, but not their claim that the final scotopic threshold is also degraded.

All of McFarland and Evans's subjects had worse scotopic thresholds under hypoxia. Several of our subjects actually had better threshold during hypoxia. The explanation may lie in the suggestion of Wald et al. (1942) that hyperventilation in response to hypoxia increases visual sensitivity. Dripps et al. (1947) observed that half of their subjects experienced a significant increase in pulmonary ventilation when breathing 12% oxygen. Our experimental technique and the use of breathing masks may have made our subjects hyperventilate. We did not, however, measure the minute ventilation, and this is speculative.

Our subjects who had been first exposed to 12% oxygen detected the target more quickly in 21% oxygen, and more of them detected the target at the lowest range of illumination. Moreover, only 5 subjects detected stimuli in the luminance range below -3.5; thus, this range was excluded from analysis. It is interesting, however, that 4 of the 5 subjects were first exposed to 12% oxygen. The reason for this order effect is not clear and may deserve further study.

DISCLAIMER

The opinions or assertions contained herein are the private view of the authors and are not to be construed as official or as reflecting the views of the Department of the Navy or the Department of Defense.

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